warmer weather. Spring wheat seeding and potato planting were finished by the 15th.—*G. N. Salisbury.*

West Virginia.—The weather during the greater part of May was very favorable for crop growth and farm work. Plowing and planting progressed rapidly and were about completed. Oats, meadows, and pastures grew rapidly and were looking well. Wheat and rye improved greatly, but the prospect was for light yields. Potatoes made good growth, and stock was in fine condition. The prospect for apples, peaches, pears, and cherries was less encouraging, as there was considerable dropping.—*E. C. Vose.*

Wisconsin.—The progress of crops for the month, as a whole, was generally satisfactory. Winter wheat and rye and spring grains, although retarded by the cold, wet weather during the early part of the month, made substantial and healthy growth. Corn planting was delayed by the wet weather, and there was much complaint of poor germination. Meadows and pastures made satisfactory growth. Strawberries and cranberries were very promising; apples good; blackberries and raspberries promised light crops.—*W. M. Wilson.*

Wyoming.—The unusually heavy precipitation was extremely favorable for the ranges, and at the close of the month they were in excellent condition. The cool, wet weather delayed seeding somewhat and prevented rapid growth of gardens, grain, and alfalfa. Stock made good gains, but some lambs and calves were lost during the storms. Streams were high and prospects excellent for a good supply of water for irrigation.—*W. S. Palmer.*

SPECIAL ARTICLES.

STUDIES ON THE CIRCULATION OF THE ATMOSPHERES OF THE SUN AND OF THE EARTH.

VI.—THE CIRCULATION IN CYCLONES AND ANTICYCLONES, WITH PRECEPTS FOR FORECASTING BY AUXILIARY CHARTS ON THE 3500-FOOT AND THE 10,000-FOOT PLANES.

By Prof. FRANK H. BIGELOW.

In my paper on "The mechanism of countercurrents of different temperatures in cyclones and anticyclones," MONTHLY WEATHER REVIEW, February, 1903, some account was given of the construction of the auxiliary charts of barometric pressures for the United States on the 3500-foot and the 10,000-foot planes, to correspond with the daily weather map on the sea-level plane. These new charts have been prepared daily since December 1, 1902, and they have been carefully studied from that time with two purposes in view, the results of the examination being briefly stated in this paper, while the more detailed explanation will appear in Volume II of the Annual Report of the Chief of the Weather Bureau for 1903–4. The first purpose concerns the information they have given as to the actual circulation in the strata above the surface, and its relation to several theories which have been advanced to account for these local circulations, and the second has regard to the derivation of precepts useful in forecasting the weather. It is quite impossible, I presume, to convey to one who has not had an opportunity to see these upper-level charts any adequate impression of their significance to modern meteorology, or of the transformations which take place in the structure of the three systems of isobars, as a cyclone passes over the United States. They must be taken together for the best results, and the study of their *mutual* configurations and variations affords us an insight into the true cause of storm formation, which is decisive as to their nature, and is of especial interest to the intelligent forecaster.

THE STRUCTURE OF THE ISOBARS AT DIFFERENT LEVELS.

In the MONTHLY WEATHER REVIEW for January and February, 1903, several examples were given of the configuration of the isobars in cyclones on the three reference planes, and also of their resolution into two components, namely, the normal isobars of the month and the abnormal or disturbance isobars, which, when added to the normal isobars, produce the observed isobars of the date. The normal monthly isobars were taken from the Barometry Report, 1900–1901, and the separation of the two systems was made by means of a graphical construction. Our purpose was to separate the strictly local disturbance circulation from the general circulation, so far as the isobars are concerned, and to compare this component of the pressure with the wind vectors which had been derived from the cloud observations of 1896–97, a summary of which was given in the MONTHLY WEATHER REVIEW for March, 1902. To illustrate this process, Charts XII and XIII for February 3, 1903, are introduced.

Chart XII, fig. 63, gives the sea-level isobars as on the weather map for February 3, 1903; fig. 64 gives in black the isobars of the same date on the 3500-foot plane, and in red those on the 10,000-foot plane. The components are given on Chart XIII, where the black lines on fig. 65 give the normal system for February on the 3500-foot plane undisturbed by cyclonic action, and the red lines the abnormal system, which, when added to the normal, produces the black lines of fig. 64. The black lines in fig. 66 give the normal and the red lines the abnormal system on the 10,000-foot plane. Since the disturbance on the sea-level plane is not much affected by the normal system, the resolution into components is omitted. It follows that we shall properly compare together fig. 63 and the abnormal systems, or red lines, on figs. 65 and 66 when discussing the theory of cyclonic gyrations. In the course of the year numerous modifications of the fundamental type occur, but in all cases it is not difficult to detect what this modification is and to be certain that we are dealing with one simple, natural structure to which every theory must conform to become acceptable.

In order that we may concentrate attention more closely upon the primary structure, which suffers numerous modifications in the local circulation, an example is given on Chart XIV of a typical system of the normal and of the abnormal isobars, such as occur in a well developed cyclone for the month of February, upon which to base certain conclusions that are in fact sustained by the entire series, without any sort of contradictory or conflicting evidence. Chart XIV, figs. 67, 68, and 69 give the normal, and figs. 70, 71, and 72 the abnormal isobars on these planes.

The discussion can not be considered complete without joining with the isobars the corresponding systems of isotherms at all three levels, but in the present stage of our study it is not possible to do this with accuracy in the higher levels. The temperature conditions in the upper strata can not be reached by direct computation, as has been done with the isobars, until a very much more extended series of actual measurements than we now possess has been made by means of balloon and kite ascensions, such as are proposed at the Mount Weather Observatory. On this account the resolution of the isotherms into their normal and abnormal exponents is now limited to the sea-level plane, or rather, to the surface of the United States. An example is taken from the map of February 27, 1903, which is reproduced on Chart XV, figs. 73 and 74, where the isotherms are printed in red. The temperature components are formed by exactly the same method as was employed in resolving the isobars, the normal temperature system being taken from the Barometry Report. Fig. 73 gives the weather map, and fig. 74 the normal and abnormal isotherms.

THE GEOMETRICAL CONSTRUCTION OF HIGH AND LOW PRESSURE AREAS.

From the study of the isobars on the three planes, it is possible to draw several important conclusions which have the value of general principles. It was shown in the MONTHLY WEATHER REVIEW for February, 1903, fig. 25, "The formation of local anticyclones and cyclones in the general circulation about the poles," that the distribution of pressure commonly observed can be approximately reproduced by the superposition of systems of concentric circles, representing positive and negative local additions to the general circles of the hemisphere concentric about the pole. The charts of the year 1903 give the actual shape of the lines as they occur in nature, which are seldom concentric circles in their form. In the cyclone they more nearly resemble ellipses, which as a family have *one* focus in common, the other retreating as the area of the ellipse enlarges. In other words the isobars are crowded together on one side of the cyclone, as the northeastern, and opened on the opposite side. I explain this fact from the circumstance that the warm area and greater bouyancy of the air is on the crowded quadrant, so that a stronger tendency to true vortex action exists there than on the cold side, where the downward flow of the air tends to diminish vortex motion, that is to decrease the abnormal pressure gradients. This can be verified by examining the abnormal isotherms of Chart XV, for February 27, 1903. The major axis of the system of ellipses is pointed forward of the axis of symmetry of the entire circulation, generally the meridian, and makes an angle α with it. All possible relations of the ellipses to the axes chosen, as $x=$ the meridian, positive southward, $y=$ the parallel, positive eastward are contained in the equation,

$$(1-e^2\sin^2\alpha)\,y^2-2\,e^2\sin\alpha\cos\alpha\,xy+(1-e^2\cos^2\alpha)\,x^2$$
$$+\,(2\,e^2\,d\sin\alpha-2\,b)\,y+(2\,e^2\,d\cos\alpha-2\,a)\,x$$
$$+\,(a^2+b^2-e^2\,d^2)=0.$$

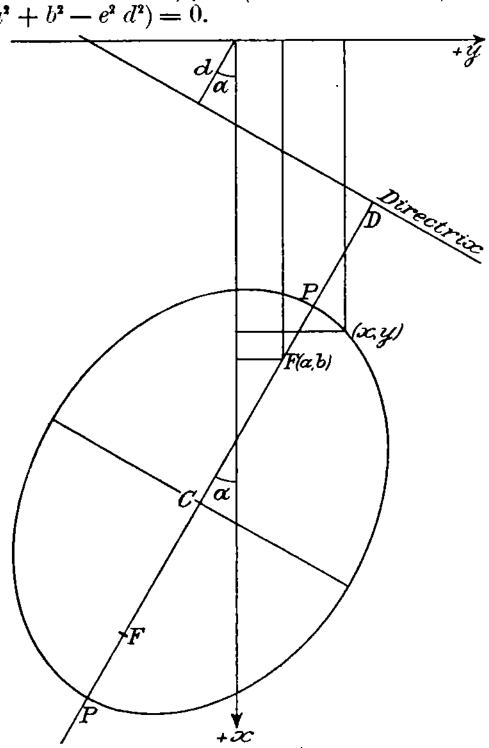

FIG. 75.—The general ellipse.

Let $(a\ b)=$ the coordinates of the focus F.

$(x\ y)=$ the coordinates of any point on the curve.

$d=$ distance of the directrix.

$\alpha=$ the angle that transverse axis ($P\,P=A$) makes with x.

$A=$ the length of the transverse axis.

$B=$ the length of the conjugate axis.

$e=$ eccentricity $=\left(\frac{A^2-B^2}{A^2}\right)^{\frac{1}{2}}$.

$FC=A\,e=$ distance focus to center.

$FP=A\,(1\mp e)=$ distance focus to vertex.

$PD=\frac{A}{e}(1\mp e)=$ distance vertex to directrix.

$CD=\frac{A}{e}=$ distance center to directrix.

A much simplified case occurs where $d=0$, $\alpha=0$, where the directrix is the axis y, and the transverse axis coincides with the axis x. For example, if $e=0.57$, $d=0$, $a=10$, $b=0$, $\sin\alpha=0$, $\cos\alpha=1$, the equation becomes,

$$y^2+0.67\,x^2-20\,x+100=0.$$

The solution gives such point pairs as (6.4, 0), (8, 4.14), (10, 5.75), (12, 6.60), (15, 7.01), etc., from which the ellipse is to be plotted.

To illustrate the composition of two systems of isobars we take that of right lines and circles.

Let $R=$ the radius of the circle,

$(a, b)=$ the coordinates of the center,

$(x, y)=$ the coordinates of any point on the circle.

The general equation of the circle is,

$$(x-a)^2+(y-b)^2=R^2.$$

If we take $b=0$ and transpose the terms,

$$y^2=-x^2+2\,a\,x+R^2-a^2.$$

The equation of the condition of the isobar which is the resultant of successive circular abnormal isobars added to successive right line normal isobars, is that the sum of certain pair numbers shall be constant on the same line. Thus, $A+B=$ constant, where $A=n\,x=$ some multiple, n, of the coordinate x, and $B=$ the gradient number on the circles. For example, take the gradient on the normal right lines one-half that on the normal circles, so that $n=\frac{1}{2}$, which is about the average in highly developed storms. Take successive circles, $R=6, 5, 4, 3, 2$, whose gradient numbers are respectively $B=0, -1, -2, -3, -4$. Take $a=6$, $A=\frac{1}{2}x$, $A+B=0$ for the 0-line and $n=\frac{1}{2}$.

TABLE 15.—*Form for computing the coordinates of the resultant curve.*

R.	B.	$A=\frac{1}{2}x$.	$y^2=-x^2+2\,a\,x+R^2-a^2$.	y coordinate.
$R=6$	$B=0$	$x=0$	$y^2=\ \ 0+0+36-36=0$	$y=0$
$R=5$	$B=-1$	$x=2$	$y^2=-4+24+25-36=9$	$y=\pm 3.00$
$B=4$	$B=-2$	$x=4$	$y^2=-16+48+16-36=12$	$y=\pm 3.47$
$R=3$	$B=-3$	$x=6$	$y^2=-36+72+9-36=9$	$y=\pm 3.00$
$R=2$	$B=-4$	$x=8$	$y^2=-64+96+4-36=0$	$y=0$

Similarly, by taking the proper groups of R, B, x, for the -1, $+1$, -2, $+2$, ... lines in low and high areas, we obtain the coordinates of the resultants. The completed computation is shown on fig. 76. "Right lines and circles, where the gradients are twice as great on the circles as on the right lines." The preceding example plots the 0-line of the low area as will be seen by the pair points (0, 0), (2, $\pm$3.00), (4, $\pm$3.47), (6, $\pm$3.00), (8, 0).

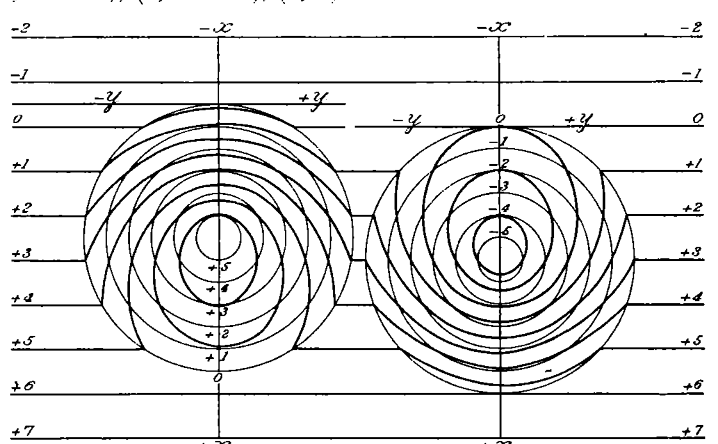

FIG. 76.—Right lines and circles where the gradients are twice as great on the right lines.

In this manner the simple cases can be readily handled analytically, and the principal is theoretically to be extended to all such groupes of curves as can be reduced to a mathematical expression. It is, however, evident that we can not obtain the equations for the observed isobars except in simplified cases, and that generally a graphical solution is all that can be employed. Practically, one takes a sheet of normal isobars and places over it a sheet of observed isobars. Then, the differences at the points of intersection are marked in the sense that so many tenths of an inch must be added to or subtracted from the normal isobar to produce the observed isobar at that point. By joining up the points of equal difference numbers the system of the abnormal isobars for the day is obtained. The axes of the negative areas, *L*, have one nearly equal angle, a, with the meridian, but the axes of the positive areas, *H*, *H*, become convergent upon two cusps, *C*, *C*, fig. 70, Chart XIV, which tend to unite over a saddle, *S*, of relatively high pressure, separating the cyclone proper *L* from the wide spread region of low pressure lying beyond the axis.

THE CUSP FORMATION AND ITS CHANGES.

Between the isobars marked 0 and —1, in all levels, there is a line of pressure which is exactly the same throughout its extent, as indicated by the line of dots on fig. 11, 3500-foot level, MONTHLY WEATHER REVIEW, January, 1903. The rounded cusps of the typical abnormal isobars of Chart XIV become sharp cusps at that pressure, in contact at a central point on the saddle, and from this line the pressure falls in two directions, but rises in two other directions as shown on the typical figures. It is evident that by raising or lowering the pressure of the entire cyclonic region, the number of the closed curves inside the cusps can be diminished or increased. For instance in intensifying the cyclone the existing cusps advance and flow together, and then separate into an additional closed curve and an additional line at the top of the figure. If the pressure is diminishing, an inclosed curve advances to meet an outside line, and joining with it produces a new cusp, but at the sacrifice of an inside closed isobar. Thus, there is continued building or destroying of the closed central isobars going on in the action of the cyclones and anticyclones of the atmosphere in proportion to the energy of the circulation at any given level. Now, on passing from one level to another along the same vertical we find a similar increase and decrease of the cusp action, showing that in the same cyclone this difference of strictly cyclonic circulation exists.

The general rule is that *the number of closed isobars steadily diminishes with the height*, as shown on Chart XIV. Our maps give this structure in all stages of the development, from energetic storms with power to penetrate to considerable heights, to shallow storms which have become entirely depleted within two miles of the ground. In the winter the cyclonic circulation is exclusively in the lower strata, and is soon stripped away by penetrating the swiftly moving general circulation of the eastward drift. A remarkable fact has been developed, namely, that as the warm weather comes on and the power of the eastward general currents diminishes, the structure of the cusps and closed isobars is maintained at very much higher elevations. Thus, in April and May the 10,000-foot level is as much involved as the 3500-foot level is in January and February. I explain this by two facts: first, that the general currents in the lower levels of January and February have retreated to higher elevations in April and May, carrying the cyclonic structure with them; second, that in the warm months there is much more surface heat to dispose of in cyclonic action than in the winter, but that it must seek higher levels to find the cold air necessary to bring about the thermal equilibrium.

In the case of hurricanes, as shown in Paper No. V of this series, the cyclonic structure is powerful at the height of the cirrus levels, five to six miles above the surface, and this is in confirmation of the results of the Weather Bureau cloud observations of 1896–97, chart 35. It was shown in the same report that, taking the entire year, the maximum cyclonic circulation is in the strato-cumulus level, two miles above the surface, whereas in the winter it is lower and in the summer higher than that level. The cusp structure then diminishes with the height, but there is *no instance in which there is any sign that the closed isobars of low pressure reverse into closed isobars of high pressure over the same center*. The closed isobars are of the same sign till they are depleted and wiped out by penetration into the eastward drift. This is a conclusion without contradiction, and it is fundamental to cyclonic theories. Since the cyclonic circulation has an inward component, as is well known to be the fact, in the lower levels, it follows that it must have an *inward component in all levels* until it is absorbed in the upper strata. There is no reversal of the gradient system of isobars in the higher level as compared with the lower level, and *there can be no outflow in the upper level of the cyclone proper* unless it can be shown that there is a reversal of the isobars. The theoretical discussions which assume a reversal of gradients in the upper portions of the cyclones have no foundation in these observations, and all such observations as claim to have found in the cloud vectors of the upper levels a true outflow (Blue Hill, Hildebrandsson and others) have apparently not made the separation between the general and the cyclonic vectors with sufficient precision to escape this incorrect inference. It should be remembered that the Weather Bureau has reached the same result by three independent lines of research: (1) From the cloud observation at 150 stations for about twenty-five years; (2) from the theodolite and nephoscope observations of 1896–97 as given in the Cloud Report; and (3) from the barometric reductions now in operation over the United States and Canada. Furthermore, the theoretical analysis in the Cloud Report makes the solutions by a reversal of gradients entirely improbable, because they depend upon the *existence of warm and cold centers*, which it is well known do not in fact occur. This is easily seen by reference to Chart XV, or to thousands of such abnormal charts in the files of the Weather Bureau. I have already explained, as in fig. 28, MONTHLY WEATHER REVIEW, February, 1903, the process by which the rising air in a cyclone is stripped off by penetrating the eastward drift, involving an interchange of inertia between the local and the general circulations. Also, some further account of the analytic conditions are contained in Paper No. III of this series. It is really very difficult to secure true normal general vectors to use in vector subtraction from the observed vectors in all the subareas surrounding a low center, and in all the cloud strata, and it is no wonder that the work at a single station should be inadequate to such a resolution of forces. Such work has also been done with the prepossession of the old Ferrel meteorology of cyclones, which is very incorrect in many particulars. An inspection of the normal and abnormal isobars of Chart XIV shows that the normal isobars give increased gradients with the height, while the abnormal isobars give diminished gradients with the height, and there is no reason why there should be reversal in either the cyclone or the anticyclone, but simple decrease in the abnormal system until complete disappearance occurs where the general system dominates in the high levels.

It should be noted that while the example of Chart XIV shows that the saddle is directed northward, there are many cases in which the opening of the cyclone is turned to the other quadrants. Thus, the saddle is found frequently in the western quadrant, occasionally in the southern quadrant, and seldom in the eastern quadrant. The opening may often swing around to the northeast, but it rarely points between east and southeast. When the saddle is to the south in the lower strata, it is likely at the same time to be pointing to the north in the upper strata, showing a complete reversal of the structure within the same cyclone as to compass direction, but there is never a gradient reversal from low pressure to high pressure in the cyclone, or from high pressure to low pressure in the anticyclone, so far as known.

CRITICAL REMARKS REGARDING SEVERAL THEORIES OF CYCLONES AND ANTICYCLONES.

From the data in the possession of the Weather Bureau regarding cyclones and anticyclones, it is proper to lay down the following propositions:

(1). Currents of air of different temperatures counterflow in the lower strata of middle latitudes to produce the cyclonic and anticyclonic circulations.

(2). The maximum and the minimum of the abnormal temperatures, that is, the warm and cold areas, are located between and not at the centers of gyration.

(3). The configuration of the local isobars, as distinguished from the isobars that sustain the general circulation, is the same at all levels and of the same type as that at the sea level.

(4). These closed isobars diminish in number with the height until they disappear in the general circulation at moderate elevations, but they do not reverse from low to high pressure or from high to low pressure with the altitude.

(5). Currents of air stream continuously through the cyclone and the anticyclone, so that the circulation involves fresh masses and not a cyclic return of the same masses.

These principles seem to be so thoroughly established that they become criteria for the validity of several proposed methods of the analysis of cyclones and anticyclones, as given in well-known papers on this subject. In case any theory should conflict with the results of observations as given, then the observations must themselves be disproved, or else some substitute found for the theory in question. Several of them were worked out years ago, and had not the advantage of our modern observations, which have materially modified the point of view.

Ferrel's cyclone.—In this cyclone a bounding cylinder is drawn around the circulating mass, excluding it from contact with fresh masses (contra 5); it requires the maximum heat for a warm center cyclone, or the minimum heat for a cold center cyclone to be distributed symmetrically about the axis of gyration (contra 2); the system of isobars undergoes reversal along the axis, as in the warm center cyclone from low pressure at the surface to high pressure above, with corresponding inflow and outflow or reversal of the radial components (contra 3 and 4).

Oberbeck's cyclone.—This cyclone requires a symmetrical distribution of temperature about the center (contra 2); an increase in the vertical velocity in proportion to the height above the surface $w = + cz$, (contra 4), whereas the diminution in number of the closed isobars with the height implies a decrease, $w = - cz$; a concentration of the closed isobars of the inner region near its boundary of separation from the outer region where $w = 0$, (contra 3) since the usual concentration in one quadrant and separation in the opposite quadrant is due to the location of the warm and cold waves and not to a dynamic circulation.

Hann's cyclone.—The theory of cyclones as eddies in as tream having *different velocities at the same level requires greater* velocity differences in latitude than the general isobars which sustain the eastward drift will admit; since the velocity differences increase with the height, eddy cyclones should especially frequent the upper strata and increase with the altitude (contra 4), but they disappear where they should be strengthening; the temperature distribution as observed can not be continuously maintained on purely hydrodynamic principles.

Hildebrandsson's cyclone.—An eddy cyclone with inflow at the bottom and outflow at the top (contra 1, 2, 3, 4) seems inconsistent with itself, if the gyratory velocity has opposite directions above and below, as claimed to have been indicated in the diagrams and observations of the Blue Hill Observatory.

v. Bjerknes's cyclone.—(Compare Arrhenius's, Kosmische Physik.) This cyclone, deduced from the line integrations, requires warm and cold centers superposed (contra 3), and distributed symmetrically about the axis (contra 2); increase of the closed isobars followed by decrease with the height (contra 4), and varous internal circuits not found in the Weather Bureau observations.

Meinardus describes stream lines based upon the Oberbeck cyclone, and the exposition has to encounter the difficulties mentioned above.

Shaw describes a special case motion quite in conformity with the stream lines in tornadoes, waterspouts, and hurricanes, but not in agreement with such a complex circulation as is found in cyclones of the United States, and typified in Chart XIV.

If these objections continue to be sustained by future observations, it follows that true analytical discussion of the forces in cyclones and anticyclones must avoid such mistaken assumptions as have been laid at the basis of much mathematical meteorology. The actual circulation is really complex in individual cases, and yet it is not difficult to see what in the main the leading principles must be. Further examination of the distribution of the temperature in the higher levels is next in the order of the research.

THE CAUSE OF THE COUNTERCURRENTS IN THE LOWER STRATA.

Ferrel's conception of the general circulation, as derived from a canal theory, where the hot air of the Tropics rises and flows toward the poles in the higher levels, fails to give sufficient account of the persistent southerly winds in the lower strata. Referring to Paper III, of this series, "The problem of the general circulation of the atmosphere of the earth," MONTHLY WEATHER REVIEW, January, 1904, the following remarks suffice. If the temperature of the Tropics is T_1 and of the temperate zone is T_2 in normal conditions, while the heat energy of the Tropics is Q_1 we shall have for the work,

$$W = \frac{Q_1}{T_1} (T_1 - T_2),$$

in average seasonal relations on the rotating earth. Since the solar insolation tends to raise T_1 to $(T_1 + \Delta T_1)$ in the Tropics, and polar radiation changes $- T_2$ to $- (T_2 + \Delta T_2)$, we shall have an increment of work,

$$W + \Delta W = \frac{Q_1 + \Delta Q_1}{T_1 + \Delta T_1} \left[(T_1 + \Delta T_1) - (T_2 + \Delta T_2) \right].$$

Where

$$\Delta Q_1 = (\lambda C_v + \mu C_v{}^1) \Delta T + A (\lambda R + \mu R_1) T \frac{dv}{v}$$

by formula 112, Cloud Report. The question depends upon the expenditure of the work ΔW, whose purpose is to restore thermal equilibrium as promptly as possible.

The Weather Bureau data show that a system of irregular currents of warm air flow from the Gulf of Mexico upon the United States in the lower strata, and are primary components in the cyclones, where mixing of the currents of air at different temperatures is taking place. These warm streams reach the place of mixture by flowing a short distance across the *general high pressure belt*, where there is no east and west velocity to complicate the action through an interchange of inertia between the normal masses and the extra currents. In the canal circulation there is on the other hand great opportunity for changes of inertia in both senses, and this the currents tend to avoid unless it is forced upon them. Thus, the warm air of the Tropics in rising first passes to strata of decreasing velocity; then, in moving northward, to strata of increasing velocity; and, finally, in descending in the temperate or polar zones, to strata of diminishing velocity. It is apparent, therefore, that the over-heated masses in the Tropics seek the temperate zone, where they encounter cooler masses, by a short and simple path rather than by a long and very complex path. The tendency for currents of high temperatures to remain individually intact as long as is possible is an additional reason for seeking the cyclonic belt by a direct path in the lower and nearly quiet strata.

Similar reasoning applied to the polar zones gives a sufficient account of the cold western current that enters the cyclone. The warm current on the eastern side underflows the eastward drift, rises into it, and allows the cold current from the northwest to flow beneath. This starts a gyration which is developed as shown by the observations described, and it continues to act as long as the feeding countercurrents of different temperatures endure. The mixture with the eastward drift propels the structure forward, and at the same time breaks up the heated air coming from the Tropics into a succession of irregular cyclones and anticyclones. The mutual reactions between the constituent parts are so numerous and so subtle that it is not easy to distinguish exactly where one set of forces, as the thermodynamic, ends, and another, as the hydrodynamic, begins. This interplay is, no doubt, responsible for the perplexity that meteorologists have encountered in establishing the correct theory of cyclonic action.

PRECEPTS FOR FORECASTING WITH THE CHARTS ON THE 3500-FOOT AND THE 10,000-FOOT PLANES AS AUXILIARIES.

The chief object in preparing auxiliary pressure and temperature charts on two planes, 3500 feet and 10,000 feet, above the sea level, was to secure three sections through the lower parts of a storm, so that their mutual relations might be studied for the purpose of improving the forecasts. They have proved to be of interest not only in theoretrical meteorology but also in forecasting, as will be more fully set forth in the full report. It has been thought proper by the Chief of the Weather Bureau to give them a practical test at the Washington office during the coming winter before deciding what emphasis shall be placed upon them. It should be clearly understood that they are intended simply to supplement the usual sea-level weather map, as auxillaries of any other kind are employed, such as the pressure-change maps, and the cloud maps now in use in forecasting. It will be necessary only to use a two-syllable code word, as the pressure-temperature word for telegraphing the fractions of the inch of pressure on the two planes, since the integral inches can readily be inferred. The study of these charts has developed many new ideas which it would be impossible to explain in a short paper, and there is no little novelty of thought involved. It will require practise to make good use of all three charts simultaneously, as they are very different from one another, but as there may be some interest in the matter among the forecast officials I have added certain precepts or brief statements, derived as the result of my own experience and studies.

1. *Direction of the storm tracks.*—These follow closely the trend of the isobars on the 10,000-foot plane, reference being made to the 10,000-foot isobars that are closely packed together and are lying well to the south of the center of the cyclones, no regard being paid to the northern curves which are distorted by other influences and represent special features of the circulation.

2. *The velocity of advance.*—This is very closely proportional to the density with which the isobars south of the cyclone are compressed, a strong gradient indicating a quick advance, while a wide gradient with straggling isobars indicates that the velocity of the movement will be slow.

3. *The areas of precipitation.*—To the eastward of the Rocky Mountain Divide these are approximately marked out by the crossing of the isobars on the 3500-foot plane at a good angle beneath those on the 10,000-foot plane. This is especially true of the months from November to April, inclusive. In the summer months, May to October, if the two sets of isobars are crowded together and nearly parallel, there is probability of rainfall in the midst of them. This rule seems to be nearly true for the north Pacific and north Plateau districts throughout the year. The relative positions of the low areas and the high areas is of great significance. On the Pacific coast when a high area is to the south and a low area to the north, these crowded isobars bring precipitation when they run directly from the ocean to the land. If the high area is well to the north, with the low area far inland, and the isobars run from the northwest or north, the tendency to cause precipitation is much diminished. The area of precipitation is on the *western* side of the cyclones of the middle and north Plateau districts, but it shifts to the *eastern* side as the cyclone passes over the Rocky Mountain slope. This makes difficult the forecasting for precipitation in the States of the slope.

If the cyclone is on the southern Plateau or the southern slope and a high area is to the eastward in the Gulf States, the 3500-foot isobars usually open out widely to the south and the region of the underflow marks out the precipitation area very definitely. If the cyclone is located far to the north, over the Missouri Valley, the southern ends of the 3500-foot isobars are usually smooth, unbroken curves, and although there may be a well-marked underflow region, the precipitation area is to be made much smaller than in the preceding case and placed well around on the north side of the cyclone. The precipitation area is apt to be confined to the closed isobars surrounding the center. The difference between these cases lies in the fact that the underflowing current in the southern cyclone is full of moisture from the Gulf of Mexico, but in the northern cyclone it is much drier, even to the extent of being without precipitation. The two types here mentioned will require study and practise for their differentiation, but a working knowledge of the difference is easily acquired. When the cyclone is east of the Mississippi River, its passage eastward or northeastward is closely controlled by the 10,000-foot plane isobars. If the cyclone is on the Atlantic coast, a high-pressure area following it from the southwest should be interpreted as meaning that a rapid clearing will follow over the region of precipitation in the rear of the cyclone. When the cyclone is over the Lake region and a second depression is over the Gulf of St. Lawrence, if the isobars loop northward over the Middle States between the two lows, the area of precipitation is quite general from New England to Minnesota.

4. *Penetration into the higher levels.*—In the winter months, December to March, the heads of the cyclones do not penetrate very much above the two-mile level, but in the summer months, June to September, they are apparently about four miles high. In these seasons, respectively, the power of an individual storm is measured by its penetration into the higher levels and is proportional to it. In the winter the upper strata are cold and drift rapidly eastward, and these two causes deplete the intruding cyclonic head; in the summer the cool strata are much higher and they move slowly, so that an uplifting cyclone finds little to check its development. This principle is seen, also, in the action of cumulo-nimbus clouds in summer. Allowing for relative differences of the seasons, the action of the upper strata upon cyclones is always essentially the same.

While there are several such general principles as these to be acquired by practise, it is yet true that the distinctive weather types are fewer in number and simpler in form on the 3500-foot and the 10,000-foot planes than on the sea level, and apparently their action is much less fluctuating and deceptive. This is a decided advantage in studying the forecast problems, which now suffer by their great complexity on the sea-level plane. In any preliminary study of the new charts there is likely to be some confusion of mind, due to the novelty of the isobaric structure and the intrinsic differences of configuration between the several planes. This mental state will be cleared up by practise, and it will be found that a real addition has been made in the understanding of the prevailing storm action. Further advantage to be derived from an introduction of the isotherms on the upper planes will probably increase the efficiency of this system in other ways.